NASA LANGLEY RESEARCH CENTER,
FULL-SCALE WIND TUNNEL
Hampton (INDEPENDENT City)
~~Hampton County~~
Virginia

HAER No. VA-118-A

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Historic American Engineering Record
National Park Service
U.S. Department of the Interior
1849 C St., NW Room NC300
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HISTORIC AMERICAN ENGINEERING RECORD

NASA LANGLEY RESEARCH CENTER, FULL-SCALE WIND TUNNEL

HAER NO. VA-118-A

Location:	643 Thornell Avenue, NASA Langley Research Center, Hampton, Virginia
UTM Coordinates:	USGS Universal Transverse Mercator Coordinates:

	Northing	Easting
A	4104961.86	380853.71
B	4104836.24	380799.77
C	4104867.60	380737.01
D	4104987.82	380790.97

Quad: Hampton, Virginia, 1:24000

Dates of Construction:	1929-1931
Engineers:	Smith J. DeFrance, Abraham Silverstein, Clinton H. Dearborn
Present Ownsr:	National Aeronautics and Space Administration(NASA) Langley Research Center Hampton, Virginia 23665-5225
Present Use:	Decommissioned
Significance:	The facility allowed wind tunnel research into fields that could be most effectively investigated with full-scale models and actual aircraft. Until 1945 it was the largest wind tunnel in the world. "Drag cleanup tests" performed here on most World War II military aircraft significantly improved their performance. The facility was used to test a variety of vehicles including military aircraft, dirigibles and submarines. The original tunnel design proved to be versatile and as ths study of aerodynamics advanced it was used to study handling problems of hypersonic aircraft and space reentry vehicles. In the 1960s and 1970s the tunnel was modified and equipped for dynamic free-flight model testing. When the facility was closed in September of 1995, it was NASA's oldest operating wind tunnel. Many achievements of the American aerospace industry can be traced to the aeronautical research performed in the full-scale tunnel.
Project Information:	This documentation was initiated July 17, 1995 in accordance with a Memorandum of Agreement with the National Aeronautics and Space Agency and the National Park Service.

This recording project is part of the Historic American Engineering Record (HAER), a long-range program to document historically significant engineering and industrial works in the United States. The HAER program is administered by the Historic American Buildings Survey / Historic American Engineering Record Division (HABS/HAER) of the National Park Service, U. S. Department of the Interior. The National Aeronautics and Space Administration (NASA) - Langley Research Center Recording Project was cosponsored during the summer of 1995 by HABS/HAER under the general direction of John Burns, Deputy Chief, and by the Langley Research Center, Paul F. Holloway, Director.

The field work, measured drawings, historical reports, and photographs were prepared under the direction of Eric N. DeLony, Chief, HAER, and project leader Dean A. Herrin, PhD. The recording team consisted of Charissa Y. Wang and Donald M. Durst, Principals/Partners - Hardlines: Design & Delineation. Robert C. Stewart, Industrial Archaeologist, West Suffield, CT produced the historical report. Jet Lowe, HAER, was responsible for large-format photography.

Others who have contributed their time, advice, documents and help were: Brad Ball (GIS Team Leader); Cyler W. Brooks Jr. (ADYD Transonic Aerodynamics Branch); Charlie Debro (FST Building Coordinator); Dana Dunham (FST); Charles D. Harris (ADYD Transonic Aerodynamics Branch); Ron Harvey (Langley Research Center Public Affairs Office); Rick Hoff (LaRC Photo Lab); Richard Layman (Historical Program Coordinator); John Mouring (Facilities Systems Engineer); Gene Nutall (Towing Tank Supervisor); Bill Salyer (LaRC Photo Lab). Jay Waravdekar, GIS Analyst, provided the UTM coordinates for the facility.

Historian: Robert C. Stewart January 1995

For additional NASA Langley Research Center information see:

HAER No. VA-118-B -	NASA Langley Research Center, 8-Foot High Speed Wind Tunnel
HAER No. VA-118-C -	NASA Langley Research Center, Seaplane Towing Channel
HAER No. VA-118-D -	NASA Langley Research Center, 8-Foot Transonic Pressure Tunnel

CONTENTS

Introduction - Wind Tunnels as Research Tools:

Mankind has had an obsession with flying since the dawn of recorded history. The legends of Icarus and Daedelus provide evidence that the ancient Greeks fantasized about soaring with the creatures of the air. The ancient Chinese very possibly did more than dream about flying. The earliest specific description of actual flight in a manned kite occurs in 559 BC[a1] during the reign of the Emperor Kao Yang.

Lighter-than-air machines offered one way to become airborne. The Montgolfier brothers accomplished the first documented flight of a hot air balloon on June 5, 1783 at Lyons, France. Their work ultimately led to passenger carrying, lighter-than-air craft. Some pioneering 19th-century aeronauts studied the flight of birds and configured early flying machines after bird-like structures. Ornithopters, as this class of machine was called, failed miserably. Aviation's earliest inventors quickly realized that they knew little about the forces acting on structures capable of flight and it became apparent that a scientific investigation of these forces, predominately lift and drag, was needed.

The earliest experimenters had no scientific data on which to base aircraft designs. To study lift and drag, investigators needed instrumentation which would quantify results of testing under controlled conditions. Those requirements spawned the wind tunnel, a tool which could measure the forces acting on an aircraft and measure its stability and controllability. To this day the wind tunnel is still an essential device for the design and development of aircraft.

One of the largest concentrations of wind tunnels for research, experimentation and analysis is at the National Aeronautics and Space Administration's Langley Research Center in Hampton, Virginia.

Flight Testing and Aircraft Development:

The earliest aviation experimenters quickly recognized that natural winds were too erratic and unsettled for evaluating their inventions. The earliest test models were mounted on windy ridges or in cave openings where relatively constant winds were found. Both Leonardo da Vinci and Isaac Newton understood that there were two ways of testing models. A prototype aircraft could be either propelled through the air or a stationary model could be suspended in a moving airstream at the required velocity. Early investigators used both methods.

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[a]Emperor Kao Yang who reigned in Northern China between 550 and 559 BC exterminated his enemies by throwing them from the top of a 100 foot tower. "He caused them ... to be harnessed with great bamboo mats as wings and ordered to fly to the ground." By the conclusion of his reign he was constantly using condemned prisoners as test pilots for man flying kites. One prince of Wei was able to fly to the ground successfully about two miles away. He was recaptured and starved to death[1].

The first mechanical device for moving a test model through the air was a whirling arm. Benjamin Robins (1707-1751) built a machine with a 4 foot long arm which was spun by a weight and pulley mechanism. Robins spun various shapes fixed at different orientations. He determined that shapes did not always have the same air resistance or drag, even though they presented the same area to the airstream. This was at variance with an earlier Newtonian theory.

Sir George Caley (1783-1857) also used a whirling arm for his experiments. In 1804 Caley built a small glider that may well have been the first successful heavier-than-air vehicle ever made[2]. Caley designed several innovative flying models. However, his major contribution was the concept that lift and forward motion of an aircraft should be treated as separate functions. That is, an engine would be used to create forward motion; this forward motion would consequently create lift by means of an airfoil or wing. The separation of lift and forward motion was a revolutionary concept and it directed research away from ornithopter concepts.

The early experimenters noted that the whirling arm device was not without its shortcomings. As the arm whirled, it would set the surrounding air into motion. Consequently, models always flew in turbulent air and the relative velocity between model and moving air could not be determined. Better test devices were needed. The improvements came in the form of a "wind tunnel."

Early Wind Tunnels:

A wind tunnel is simply a tube or passage through which a stream of stabilized air is forced by a propeller or fan. The wind tunnel is a form of analog computer with which an engineer can optimize aircraft design[3]. A scale model of the aircraft to be evaluated is mounted in the test section of the wind tunnel. The effect of the air stream on the aerodynamic qualities of the model is monitored and measured by force sensors and test instrumentation. The wind tunnel's ability to accomplish testing in a controlled environment rapidly made the whirling arm devices obsolete.

The aerodynamic forces acting on an aircraft in flight are *lift, drag* and *side force*. The drag force is a force opposite to the flight path, it retards the aircraft; the lift and side forces are at right angles to the flight path. Lift counters gravity and is crucial to flight. The wind tunnel and its instrumentation are able to simulate and measure these forces.

Frank H. Whenham (1824-1908) designed and operated the first wind tunnel in 1871. A steam engine, upstream of the model, drove a fan which pushed air down an 18 inch square tube to the model. Whenham's experiments indicated that at low angles of incidence, lift to drag ratios of airfoils were relatively high, approximately a ratio of 5:1 at a 15° angle of attack. With such magnified lift to drag ratios, substantial loads could be supported. Whenham's research also explored the effect of aspect ratio. He found that long narrow wings contributed much more lift than stubby wings, even when the surface area was the same. The next problem was determining whether experimental results obtained on a 1/10th scale models could apply to a full-sized aircraft[4].

The wind tunnel was not the only method of acquiring flight characteristics.

During the developmental period of scientific aerodynamics, experimental information for resolving aerodynamic questions had been obtained from flight tests, drop tests, rocket sleds, water tunnels, shock tubes, whirling arms, water tables, rocket flights, flying scale models and ballistic ranges. Wind tunnels may be subsonic, nearsonic, transonic, supersonic and hypersonic[b]. These facilities are located all over the world[c]. There are also special purpose wind tunnels for testing aircraft spin characteristics and icing. In addition other specialized non-aircraft tunnels are used in meteorological experiments, evaluating building designs, designing windmills, evaluating automobile shapes and testing skiers and skydivers.

Wind Tunnel Technology:

When an aircraft moves through air, the air viscosity, elasticity and gravity create forces which act on the aircraft. The important force ratios, named after their discoverers, are Reynolds number, Mach number and Froude number. Low speed wind tunnel tests are significantly influenced by Reynolds number effects.

If a model test has the same Reynolds and Mach numbers as the full scale aircraft, then the flow about the model and the full scale aircraft will be identical; the forces and moments generated by the model can be directly scaled up

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[b]Subsonic - up to Mach 0.4; Transonic up to Mach 1.3; Supersonic up to Mach 4.0 to 5.0; hypersonic greater than Mach 5.0 (Pope 1954:37).

[c]The nations of the world support aeronautical research, of which wind tunnel testing is a major item, according to their abilities and desires. Usually each nation sets up a separate organization that augments the activities of the armed services, and further work is farmed out to universities and industry. In the United States this central agency is the National Aeronautics and Space Administration, with offices in Washington, D.C. and whose laboratories are at the Goddard Space Flight Center in Maryland, the Langley Research Center in Virginia, the John F. Kennedy Space Center in Florida, the Marshall Space Flight Center in Alabama, the Mississippi Test Facility in Mississippi, the Manned Spacecraft Center in Texas, the Lewis Research Center in Ohio, the Flight Research Center in California, the Ames Research Center in California, and the Jet Propulsion Laboratory in California.

In addition the armed services have tunnels of their own. The Air Force has several at Wright-Patterson AFB, Ohio, and at Arnold Engineering Development Center, Tennessee. The Navy has tunnels at the David Taylor Naval Ship R&D Center in Carderock, Maryland and the Naval Ordnance Laboratory at White Oaks, Maryland. The Army has tunnels at the Aberdeen Proving Grounds, Maryland and Ames Research Center, California. In addition, nearly every aircraft corporation has at least one wind tunnel.

Source: 1954 Wind Tunnel Testing-2nd edition; Alan Pope Wiley, New York to the full sized aircraft[d]. In low speed tests, Reynolds number effects predominate while Mach numbers are critical in high speed testing. The Froude number is of consequence chiefly in free-flight or spin testing.

There are two basic types of wind tunnel, open circuit and closed return. In an open circuit tunnel, the air follows a straight path from the entrance through a constriction to the test section, diffuser and fan section to an exhaust. The test section may be open (Eiffel type) or it may be enclosed (closed jet).

Alternatively, a tunnel may be the closed return type. In this tunnel the air circuit is continuous. Most tunnels have a single return path for the air however, tunnels with double return paths have been built, one of which is a subject of this report. The closed circuit tunnel may have either a closed or open test section[5].

The Origins of the National Aeronautics and Space Administration:

The present National Aeronautics and Space Administration (NASA) was established in 1958 as an expansion of an earlier agency, the National Advisory Committee on Aeronautics (NACA). NACA's mission was oriented to the practical solution of engineering problems facing the aircraft industry and the military. The account of how NACA, its research facilities and wind tunnels came into being is a vital part of the history of aviation technology.

For several years after the Wright brothers proved that a flying machine was feasible with their first flights in 1903, American interest in their accomplishment languished. Five years elapsed before their achievement was recognized. Ten years after their first flight, the "flying machine" was still a novelty. Nevertheless, practical passenger carrying aircraft capable of being airborne for three or four hours had been developed by 1911[6]. In Europe, tradition advanced the institutionalization of science and major aeronautical research programs were initiated before the start of World War I. European militarists realized that the airplane had potential uses in battle and funded research to develop combat and reconnaissance aircraft.

At the inaugural meeting of the American Aeronautical Society in April 1911, several members endorsed the idea of developing a national aeronautics laboratory. Bureaucratic squabbling and the inability of governmental leaders to see aeronautics as a new technology with vast potential for American business slowed acceptance for the concept. Continual urging from Charles Doolittle Walcott, Secretary of the Smithsonian Institution, and others led to the creation of an advisory committee for aeronautics. Congress passed a proposal to create the committee on March 3, 1915.

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[d]Reynolds number can be increased by raising the tunnel pressure. However this places greater loads, stresses and deflections on the model. Velocity is generally linked to the airspeed at which the model is being evaluated and cannot be changed arbitrarily. Model length is related to the size of the tunnel. Gases other than air have been used but results vary from those usually obtained in air. Viscosity is the only parameter left to be adjusted. It can be reduced by lowering air temperature.

The House Committee on Naval Affairs was favorably disposed and attached the National Advisory Committee for Aeronautics (NACA) charter as a rider to a naval appropriation bill. NACA was funded with an appropriation of $5000[7].

Land was acquired in Hampton, Virginia and NACA broke ground for its first laboratory building on July 17, 1917. The new installation was named after Professor Samuel P. Langley of the Smithsonian, one of aviation's pioneering researchers.

The Wind Tunnels at Langley:

The new Langley Memorial Laboratory (LMAL) had essentially no experience in wind tunnel design and operation. The first Langley tunnel was a near duplicate of a small tunnel at the British National Physical Laboratory. The tunnel had no return circuit and was powered by a 200 horsepower electric motor which provided winds of up to 90 mph[8]. This tunnel was regarded as a learning device; it did not provide data for aircraft design.

During the pioneering period of aerodynamic research, engineers found that the flight characteristics of a small model could not be directly applied to a full-sized airplane without using a correction factor. Models and full-sized aircraft behaved differently under dynamic conditions. Reynolda number of 1/20th sized scale models being tested at operational airspeed would be too low by a factor of 20. However, aince the Reynolds number is proportional to air density, models teated at 20 atmospheres would yield a Reynolds number identical to those obtained in full-sized testing. This method was successfully used in NACA's variable-density wind tunnel (VDT) where tests were conducted at the same Reynolds number as would be experienced in flight[e].

The variable-density wind tunnel offered a satisfactory means for testing the component parts of an airplane and was particularly suitable for conducting fundamental research on experimental airfoil sections and streamlined bodies. It achieved a distinguished reputation in international aeronautical circles[f]. However,

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[e]Langley's early reputation as an renowned research facility rested on the work done at its variable denaity wind tunnel. Max M. Munk, a distinguished German aerodynamicist, was retained by NACA as a technical assistant to enhance the scientific and theoretical aspects of its work. Munk and the Langley engineering staff developed a pressurized wind tunnel in 1921. With the use of a pressurized tunnel and scale models, the engineers were able to develop a range of airfoil shapes and catalog their characteristics. This was a significant step in applying rigorous theoretical knowledge to developing practical wing shapes.

[f]The scientific community appreciated the valuable aerodynamic research data being produced. *The Aeroplane of London* asserted:

> The only people so far who have been able to get at something like accurate results from wind tunnel experiments are the workers at the experimental station at Langley Field. . . .

the VDT could not evaluate ths aerodynamic characteristics of a complete airplane. It was not equipped to answer questions about how rotating propellers affected aircraft controllability. Intsrference effects created by aircraft components could not be quantified. Perhaps most significantly, drag penalties due to external struts, surface gaps, air lsaks and engine cooling installation could not be effectively assessed with models.

Realistically, it was impossible to build a model of the required size that would be a true reproduction of an entire airplane. In addition, for wind tunnel testing, any models had to be designed to withstand large forces. The strength of available materials would not allow scale-down to acceptable sizes.

In view of the limitations of the VDT, the alternative was to test experimental full-sized aircraft in flight or build a tunnel large enough to test a full sized aircraft. There was a clear-cut need for a full-scale tunnel. Prior experience with the Propeller Research Tunnel, a large-scale facility, demonstrated that a full-scale tunnel could be built. Because of the variation in atmospheric conditions, flight testing required many check flights to average out the variance in data. Alterations suggested by flight tests were often limited to those that did not significantly influence the weight or airworthiness of the airplane. To provide a means of full-scale investigation under controlled conditions and alterations made without serious limitations, NACA built a full-scale wind tunnel (FST).

The Full-Scale Wind Tunnel:

The Full-Scale Wind Tunnel is located in the city of Hampton, Virginia at the Langley Research Center of the National Aeronautics and Space Administration (NASA). The boundary of the facility is defined by the outside perimeter of Building 643 in the East Area of the Langley Research Center. The legal description of the property is located at NASA's Real Property Management Office, Code NXG, Washington, D.C. 20546.

NACA authorized construction of a full-scale wind tunnel in February of 1929[9]. Under the leadership of Smith J. DeFrance, a design team began work in the spring. Other key members of design team were Abraham Silverstein, Harry J. Goett and Clinton H. Dearborn[9]. DeFrance, Silverstein and Goett eventually became NACA/NASA Center Directors[10].

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[9]The Main Committee of the NACA met in Washington, D.C., twice a year, the annual meeting being held in October and the semiannual meeting in April. Among the matters discussed at the semiannual meeting on April 18, 1929 was the forthcoming construction of a full-scale wind tunnel and a seaplane channel at Langley. Present were: John F. Victory, secretary; Dr. William F. Durand; Dr. Orville Wright; Dr. George K. Burgess; Brig. Gen. William E. Gillmore; Maj. Gen. James E. Fechet; Dr. Joseph S. Ames, chairman; Rear Adm. David W. Taylor, USN (Ret.), vice chairman; Capt. Emory S. Land,- Rear Adm. William A. Moffett; Dr. Samuel W. Stratton,- Dr. George W. Lewis, director of aeronautical research; and Dr. Charles F. Marvin.

The full-scale wind tunnel was used to determine the lift and drag characteristics of a complete airplane. Engineers were able to study the control and stability characteristics of an aircraft both with and without the slipstream. It would also allow the study of body interference with air flow. A moveable bridge permitted technicians to position direction and velocity of flow sensors at any point around an airplane. Aircraft engine cooling and cowling problems were also investigated under conditions similar to those in flight.

The FST was to be the first wind tunnel constructed with an elliptic throat and with two propellers mounted side by side. A 1/15th scale model was constructed to study possible flow problems. The scale model confirmed that the design was practical. This device was later used for small scale testing.

An initial appropriation of $900,000, allotted before the start of the great depression, allowed NACA to purchase materials and labor at deflated prices. There was a pool of skilled engineers and laborers available and the work started in the spring of 1930. The tunnel was operated for the first time on May 27, 1931 during the 6th Annual Aircraft Engineering Conference[11]. It is housed in building 643, East Area of Langley Research Center.

The FST is of the double-return flow type. That is, the airflow from the dual propellers was split right and left into two streams. Doubling back between the test section and the building's wall, the streams reunited prior to the throat of the test section. The tunnel has a 30 by 60 foot open throat at the test section. On either side of the test chamber is an air return passage 50 feet wide, with a height varying from 46 to 72 feet. The outside walls of the building function as the outer walls of the return passage. The air is circulated by two propellers 35 feet 5 inches in diameter, located side by side, and each directly connected to a 4,000-horsepower slip-ring induction motor.

The original motor control equipment permitted varying the speed in 24 steps between 25 and 118 miles per hour. Later modifications limited speed to 100 mph[12]. The FST was equipped with a 6-component balance for obtaining the forces in 3 directions and the moments about the 3 axes of an airplane. The struts linking the aircraft to the balance were streamlined to minimize interference with the air stream. Force data from all scales was simultaneously recorded at preset intervals.

When the tunnel was calibrated tests showed that the dynamic-pressure distribution in the test section was within ± ½ percent of a mean value[h]. The FST air stream had a very small amount of turbulence. Subsequent aircraft flight tests agreed with test data obtained in the tunnel.

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[h]Based on the mean velocity of 118 miles per hour at the jet, the ratio of the kinetic energy per second to the energy input to the propellers per second is 2.84. Since a long open jet is a source of energy loss, the above figure was considered very satisfactory.

Technical Description of the Full-Scale Tunnel:

The following description of the tunnel is excerpted from Smith J. DeFrance's report Number NACA TR-459[13]. The final report was published at the conclusion of the construction and evaluation of the project on March 13, 1933.

Dimensions/Materials:

The over-all length of the tunnel is 434 feet 6 inches, the width 222 feet, and the maximum height 97 feet. The building framework is of structural steel and the walls and roof are of 5/16-inch corrugated cement asbestos sheete (Carrystone). The entrance and exit conee are constructed of 2-inch wood planking, attached to a steel frame and covered on the inside with galvanized sheet metal as a protection against fire.

Entrance Cone:

The entrance cone is 75 feet in length and in this distance the cross section changes from a rectangle 72 by 110 feet to a 30 by 60 foot elliptic section. The area reduction in the entrance cone is slightly less than 5:1. The shape of the entrance cone was chosen to provide constant acceleration to the air stream and to retain a 9-foot length of nozzle for directing the flow.

Test Chamber:

The test chamber, in which is located the working section of the jet, is 80 by 122 feet. The length of the jet, or the distance between the end of the entrance cone and the smallest cross section of the exit-cone collector, is 71 feet. 20 by 40 feet doors located in the walls of the return passage on the west side provide access for airplanes. Tracks attached to the roof trusses and running across the test chamber at right angles to the air stream and in the direction of the air stream support an electric crane for lifting the airplanes onto the balance.

Exit cone:

A smooth fairing located forward of the propellers and on the center line of the tunnel transforms the somewhat elliptic section of the single passage into two circular ones at the propellers.

From the propellers aft, the exit cone is divided into two passages. Each transforms from a 35-foot 6 ½-inch circular section to a 46-foot square over a length of 132 feet. The included angle between the sides of each passage is 6 degrees.

Propellers (Fans):

The propellers are located side by side and 48 feet aft of the throat of the exit-cone bell. The propellers are 35 feet 5 inches in diameter and each consists of four cast aluminum alloy blades screwed into a cast-steel hub. (The original aluminum propellers did not perform as expected and were replaced by wooden blades soon after the tunnel was completed.) Later nomenclature designated propellers as "fans."

Motors:

The most commonly used power plant for operating wind tunnels is a direct-current motor and motor-generator set, with a Ward-Leonard control system. For the FST it was found that alternating current slip-ring induction motors, together with satisfactory control equipment, could be purchased for approximately 30 percent less than the conventional direct-current equipment. Consequently, two 4,000-horsepower slip-ring induction motors with 24 steps of speed between 75 and 300 r.p.m. were installed. In order to obtain the range of speed, one pole change was provided. Other variations were obtained by the introduction of resistance in the rotor circuit. This control permitted a variation in air speed from 25 to 118 miles per hour. The two motors are connected through an automatic switchboard to one drum-type controller located in the test chamber. All the control equipment is interlocked and connected through time-delay relays, so that regardless of how fast the controller handle is moved the motors will increase in speed at regular predetermined intervals.

The motors are provided with ball and roller bearings, which reduce the friction losses to a minimum. Roller bearings of 8.5 and 11.8 inch bores are provided at the slip-ring and propeller ends respectively, while the thrust of the propellers is taken on a ball bearing at the rear end of each motor shaft. The motors are mounted with the rotor shafts centered in the exit-cone passages. The motors and supporting structure are enclosed in fairings so that they offer a minimum resistance to the air flow.

Guide vanes:

The air is turned at the four corners of each return passage by guide vanes. These vanes are of the curved-airfoil type formed by two intersecting arcs with a rounded nose. The arcs were designed to give a practically constant area through the vanes.

The vanes at the first two corners back of the propellers have chords of 7 feet and are spaced at 0.45 and 0.47 of a chord length, respectively. Those at the opposite end of the tunnel have chords of 3 feet 6 inches and are spaced at 0.41 of a chord length. By a proper adjustment of the angular setting of the vanes, an acceptable velocity distribution was obtained. No honeycomb diffuser was needed to smooth distribution.

Balance:

The balance, which is of the 6-component type, is shown diagrammatically in Figure 4. Ball and socket fittings at the top of each of the struts A hold the axles of the airplane to be tested; the tail is attached to the triangular frame B. These struts are secured to the turntable C, which is attached to the floating frame D. This frame rests on the struts E, which transmit the lift forces to the scales F. The drag gage G is attached to the floating frame on the center line and, working against a known counterweight H, transmits the drag force to the scale J. The cross-wind force linkages K are attached to the floating frame on the front and rear sides at the center line. These linkages, working against known counterweights L, transmit the cross-wind force to scales M. In the above manner the forces in three directions are measured and by combining the forces and the proper lever arms, the pitching, rolling, and yawing moments can be computed.

Dial scales were used and provided with solenoid-operated printing devices. When the proper test condition is obtained, a push-button switch is momentarily closed and the readings on all seven scales are recorded simultaneously, eliminating the possibility of human reading errors.

The triangular frame B is caused to telescope by electrically operated screws which raise and lower the tail of the airplane and thereby vary the angle of attack. By a similar mechanism the turntable C can be moved so as to yaw the airplane from 20° left to 20° right.

The entire floating frame and scale assembly was enclosed in a room for protection from air currents. Supporting struts are shielded by streamlined fairings which are secured to the roof of the balance room and free from the balance. The tare-drag measurements are therefore reduced to a minimum.

Survey equipment:
A 55-foot structural steel bridge is attached to the bottom chord of the roof trusses. This could be rolled across the full width of the test chamber. A car was mounted on this bridge and could be rolled along the entire length of the chamber. A combined pitot, pitch, and yaw tube was suspended below the car. It could be raised or lowered and pitched or yawed through gearing controlled electrically from the car. This arrangement permitted the alignment of the tube with the air flow at any point around an airplane. The alignment of the tube is indicated by null readings on the alcohol manometers connected to the pitch and yaw openings in the head. The angle of pitch or yaw is read from calibrated Veeder counters connected to the electric operating motors. This equipment was useful for studying the downwash behind wings and the flow around the tail surfaces of an airplane.

Contributions of FST Experimentation:

Drag tests in the FST revealed substantial performance penalties from external struts and other exposed components on aircraft. In April 1938 the navy believed the 250-mile-per-hour flight test performance of its new experimental fighter, the Brewster XF2A Buffalo could be improved. The Langley staff was directed to look for "kinks" or "bugs" in the plane's design and to determine, within one week, "what drag reduction may be expected from changes that can readily be incorporated in the event that this type is put into production." The FST engineers mounted the XF2A-1 on the balance of the 30 x 60-foot wind tunnel and started a painstaking drag cleanup investigation.

After five days of testing the engineers determined that Brewster designers had disregarded the aerodynamic importance of the projecting landing gear, exhaust stacks, machine-gun installation, and gun sight. The combined effect of these protrusions was to produce unacceptably high drag. By modifying the XF2A-1 to minimize the projections, the top speed of the Brewster prototype was increased by 31 miles per hour to 281, more than a 10 percent improvement in performance[14].

Practically every high performance aircraft used by the United States during World War II was routed through Langley and checked out in the FST for "drag cleanup tests." The facility operated 24 hours a day - 7 days a week during World War II.

Between April 1938 and November 1940 Langley tested 19 different military prototypes in the FST with the objective of improving performance[i]. The FST proved to be so useful that NACA built an even larger version at the Ames Research Center in 1944. The FST's huge space allowed aerodynamic testing of an assortment of other vehicles which included dirigibles, submarines, radar antennas, gliding parachutes, inflatable airplanes, and free-flying models.

The maximum air-speed of the tunnel was roughly equal to the top speed of most aircraft flying when it was built, around 100 mph. Prior to World war II the maximum speed of aircraft surpassed that of the FST. Low speed data cannot be extrapolated on to the operating envelope of transonic and supersonic aircraft. Yet transonic and supersonic aircraft operate at relatively low speeds on take-off and landing. Wing and airfoil sections designed for high speeds usually have poor low-speed characteristics. The FST was used to investigate ways of reducing poor low-speed characteristics on full or large scale aircraft[15].

The FST was completely rehabilitated after 46 years of active, useful life. In 1977, when the refurbished tunnel had been returned to operation, experiments were conducted on solutions to landing problems of the supersonic transports vehicle, a concept not even remotely envisioned by the original tunnel designers[16]. The FST was also set up for free-flight testing of subscale models. Figure 5 shows the set up for free-flight tunnel tests. High-angle-of-attack flight dynamics for advanced fighter designs were studied with free-flight models. Additional work in

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[i]Langley Drag Reduction Program

Research Authorization	Date	Airplane
603	June 1938	Brewster XF2A-1 Buffalo
606	June 1938	Grumman F3F-2
607	June 1938	Grumman XF4F-2 Wildcat
633	August 1938	Vought-Sikorsky SB2U-1 Vindicator
635	August 1938	Curtiss XP-37
636	August 1938	Curtiss P-36A Mowhawk
637	August 1938	Curtiss XP-40 Kittyhawk
646	December 1938	Douglas XBT-2
647	December 1938	Curtiss YP-37
672	June 1939	Seversky XP-41
674	June 1939	Bell XP-39 Aircobra
695	September 1939	Curtiss XP-42
698	September 1939	Grumman XF4F-3 Wildcat
709	November 1939	Curtiss XP-46
739	May 1940	Republic XP-47 Thunderbolt
746	September 1940	Chance Vought XF4U-1 Corsair
796	October 1940	Brewster XF2A-2 Buffalo
797	October 1940	Curtiss XSO3C-1
811	November 1940	Consolidated XB-32 Dominator

Source; Langley Research Authorization Files (EIC 196)

1984 included work on the electric motors powering the fans. Prior to shut-down, research was directed at low-speed aerodynamics, static and dynamic stability and control and flow characteristics of military, general aviation and commuter aircraft.

Conclusion:

The Full-Scale Wind Tunnel at Langley was the oldest operating wind tunnel within NASA when it was decommissioned. It was continuously operated for 64 years. Known in later years as the 30 by 60-Foot Tunnel, it performed its original mission of testing large aircraft at actual flight speeds. It was vital in reducing the drag of World War II fighter aircraft and its test data resulted in substantial performance improvements.

The tunnel's capabilities were improved to study flight characteristics of sub-scale models and for research on advanced and experimental designs. The Full-Scale Tunnel's contributions to aerospace technology were officially recognized in 1985, when it was named a U.S. National Historic Landmark. The FST is an outstanding example of a major NACA facility that expanded into a variety of additional uses not visualized when it was designed. It contributed to aircraft research over a period of pioneering designs from early 1930s airplanes to hypersonic aircraft and space reentry vehicles like the space shuttle.

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3 Alan Pope, Wind Tunnel Testing 2nd edition, (New York: John Wiley, 1954), 8.

4 Baals, 3.

5 Pope, 8-9.

6 James R. Hansen, Engineer In Charge, (Washington, D.C.: National Aeronautics and Space Administration, 1987), 2.

7 Ibid., 5.

8 Baals, 14.

9 Hansen, 447.

10 Baals, 23.

11 Hansen, 447.

12 Harry A. Butowsky, Full Scale Tunnel, National Register Nomination Form, (Washington, D.C.: Department of the Interior; HAER Inventory, 1984): 2.

13 Smith J. DeFrance, Report No. 459 - The N.A.C.A. Full-Scale Wind Tunnel, (Langley Field, Virginia: Langley Memorial Aeronautical Laboratory, National Advisory Committee for Aeronautics, March 13, 1933), 291-298.

14 Hansen, 195.

15 Butowsky, 2.

16 Baals, 23.

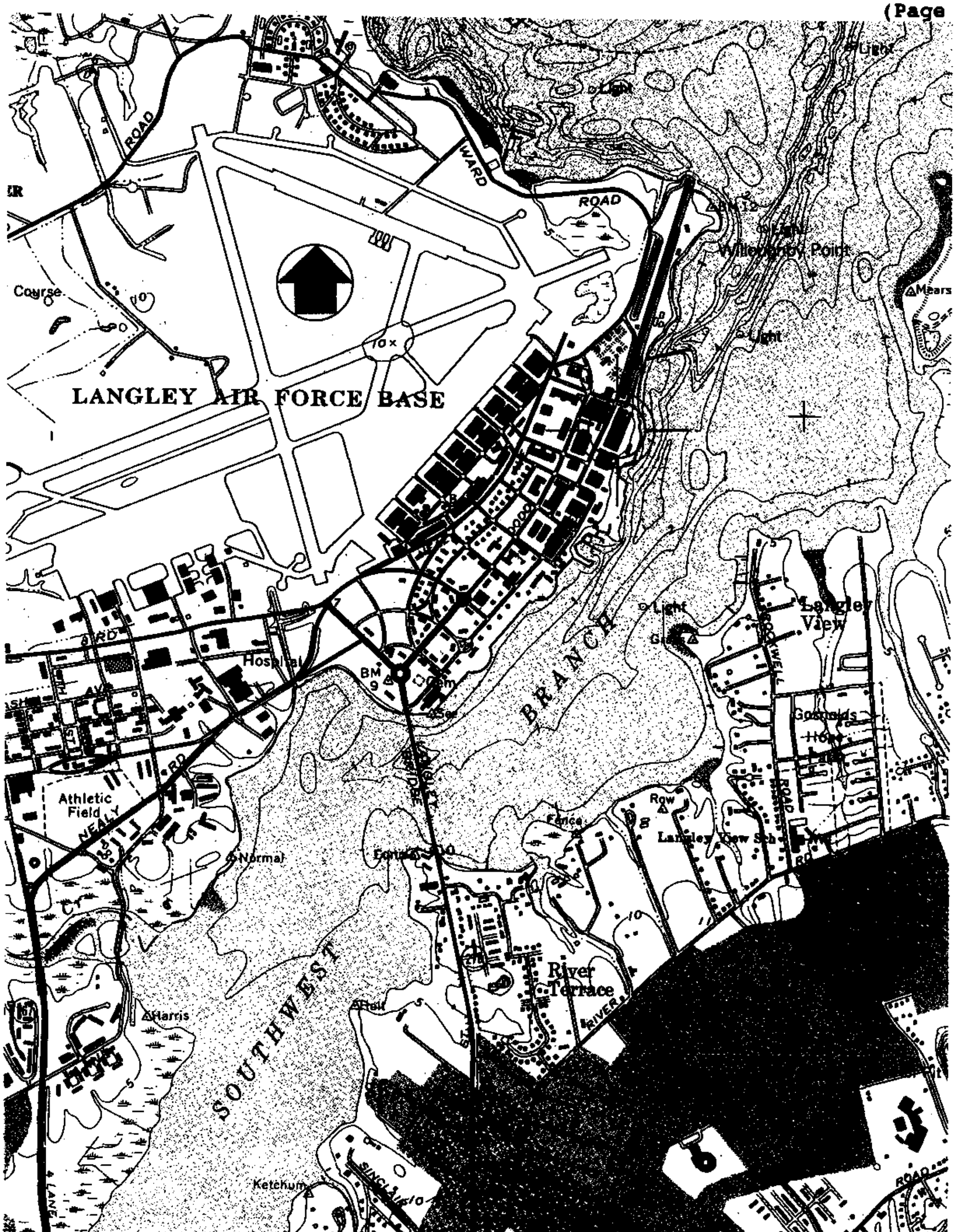

Figure 1 - Location Map
Quadrangle: Hampton, Virginia 1:24000

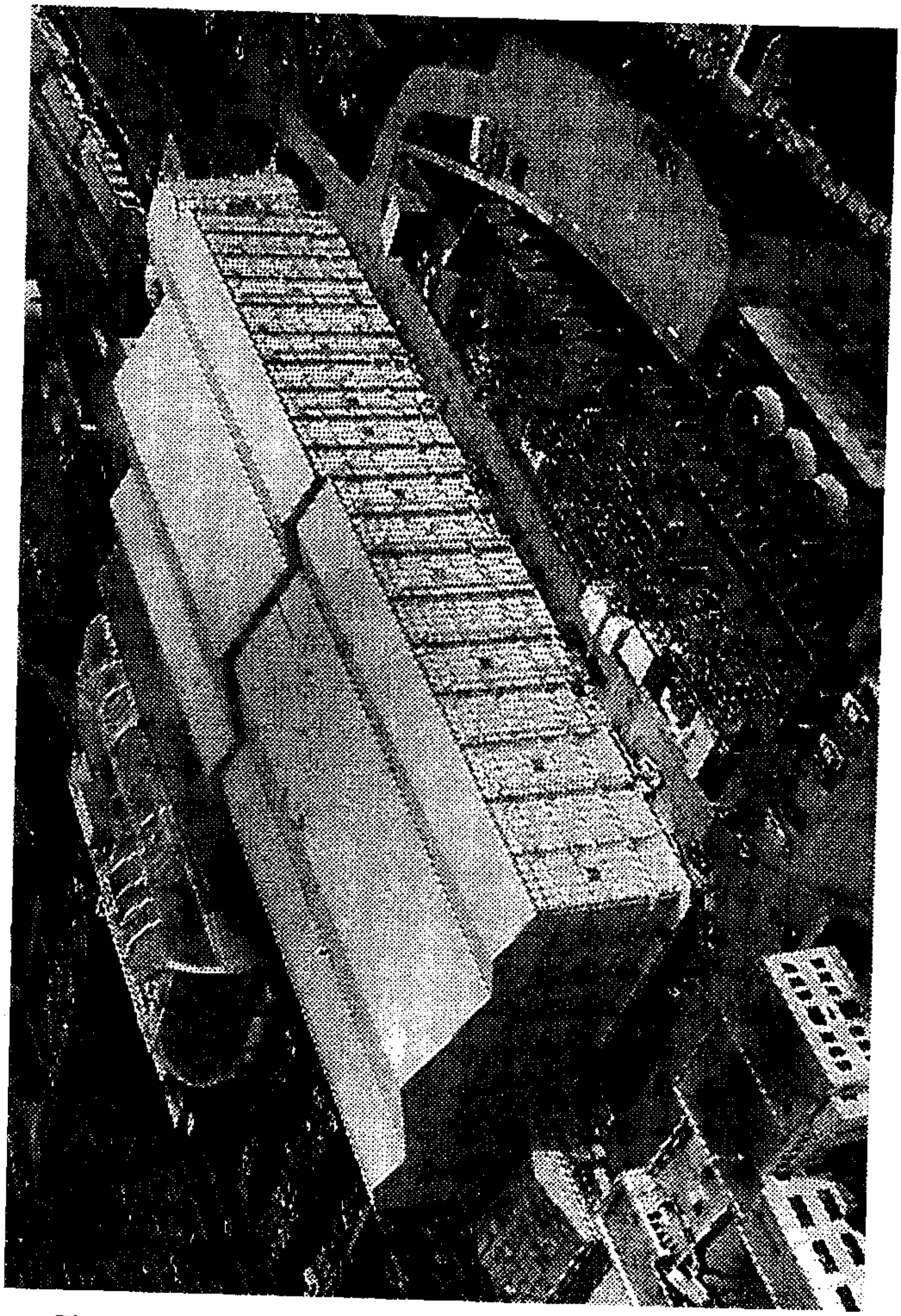

Figure 2 - Aerial view northwest of the Full-Scale Wind Tunnel - 1989
Source: NASA Langley Research Center - #L89-07075; Photographer Bill Salyer

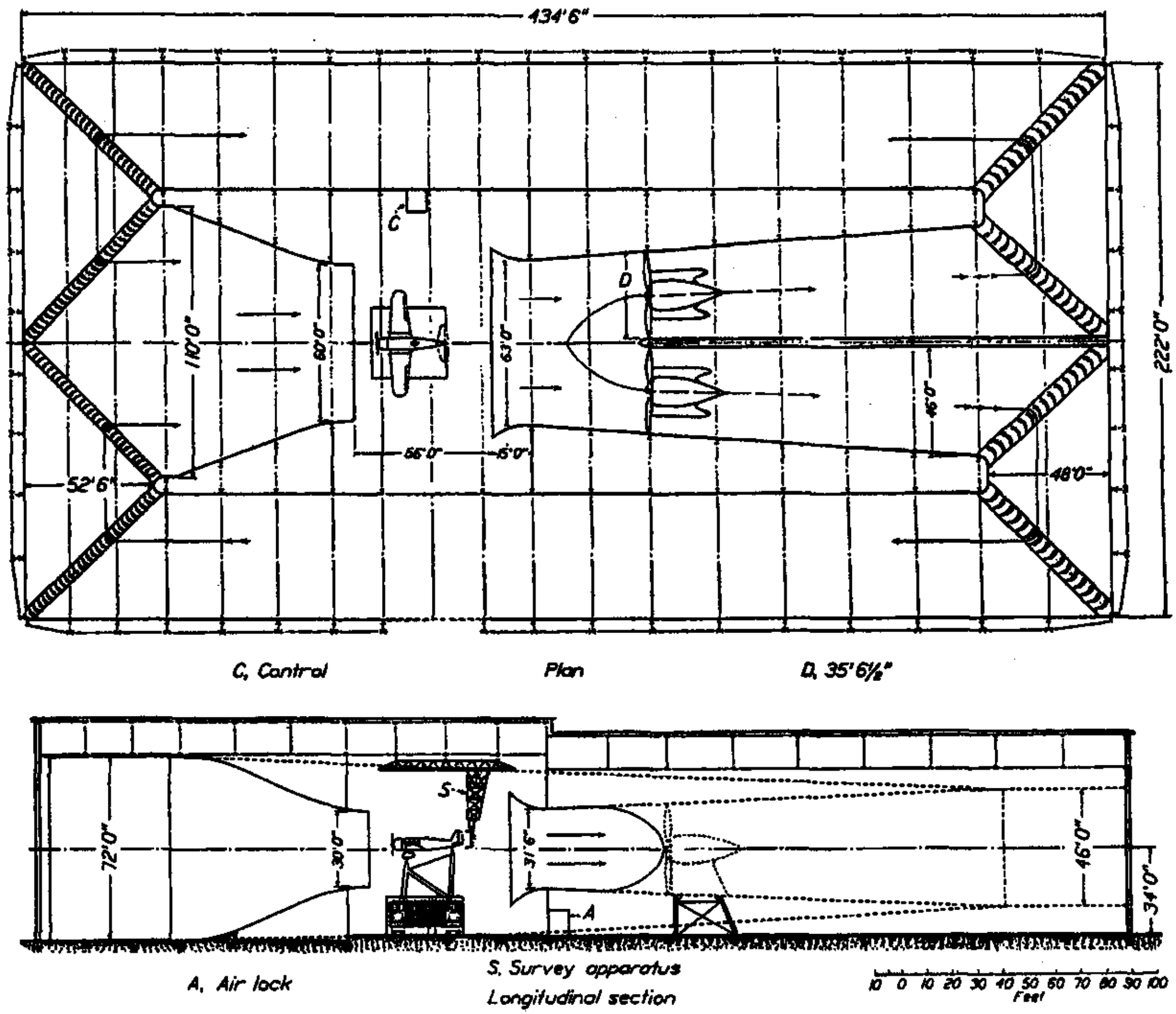

Figure 3 - Plan and Elevation, Full-Scale Wind Tunnel
Source: TR No. 459 - NACA Full-Scale Wind Tunnel

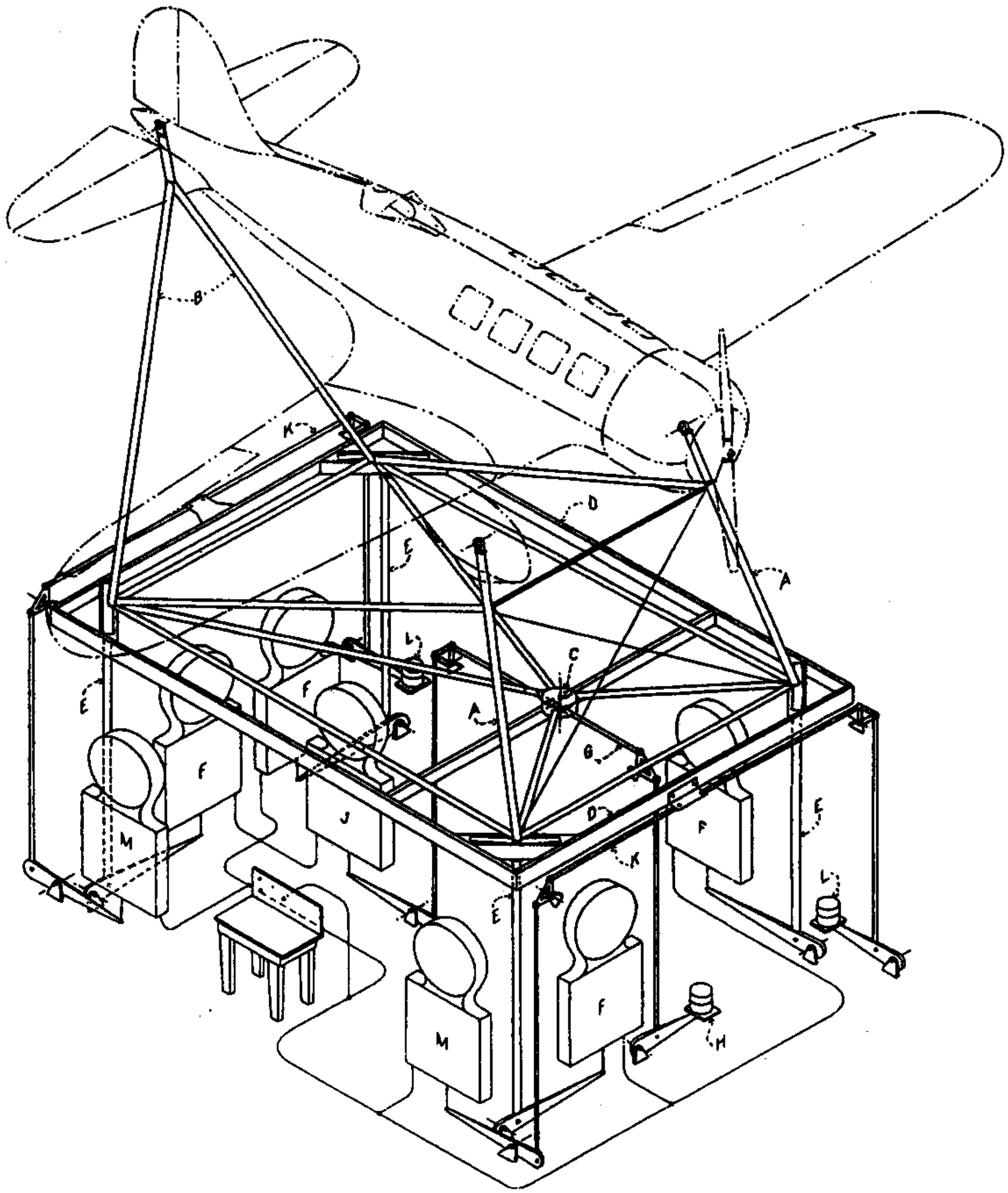

Figure 4 - Schematic Drawing of the FST Balance, Full-Scale Wind Tunnel
Source: TR No. 459 - NACA Full-Scale Wind Tunnel

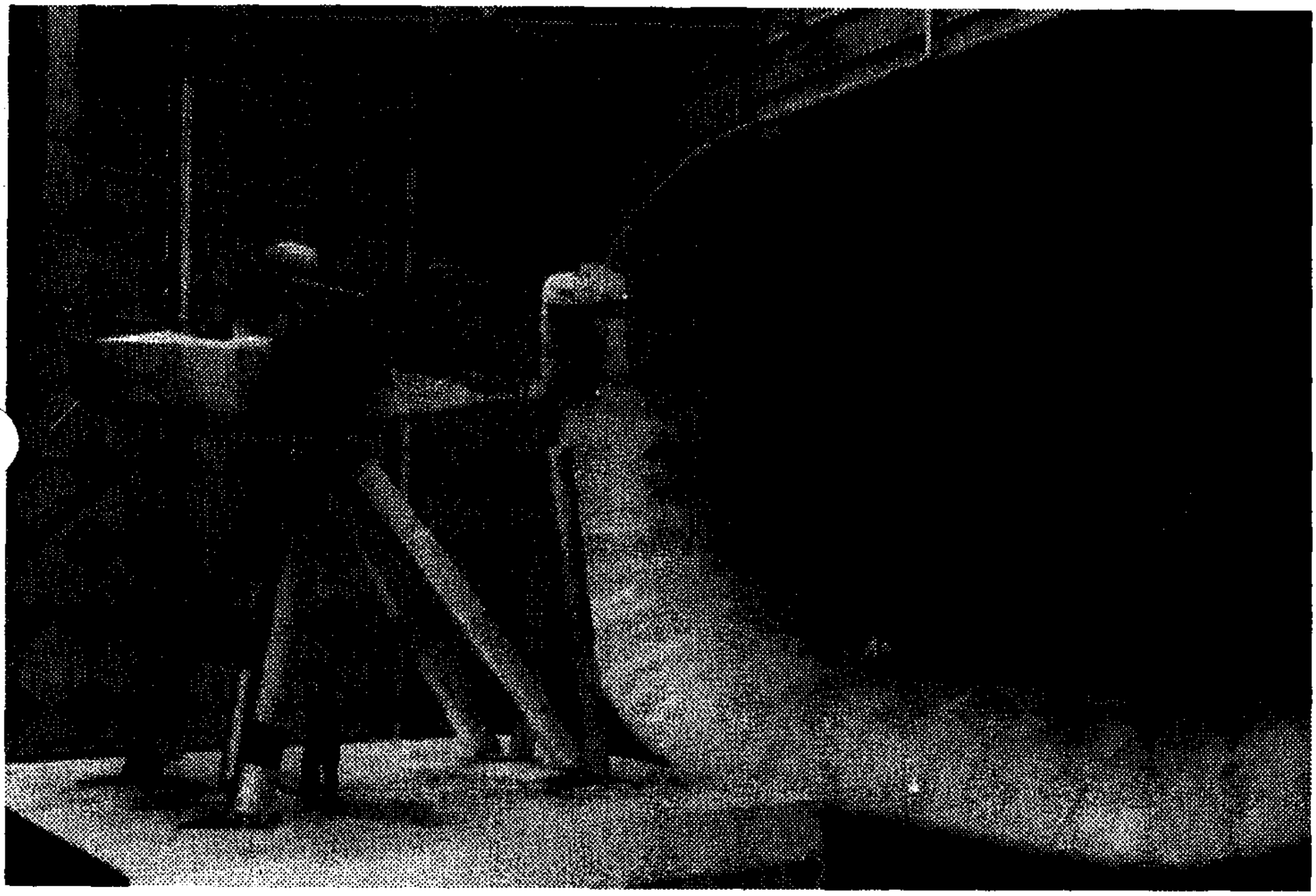

Figure 5 - Loening XSL-1 single engine Navy seaplane - October, 1931
An early test in the Full-Scale Wind Tunnel
Source: NASA Langley - Photograph # L-5925

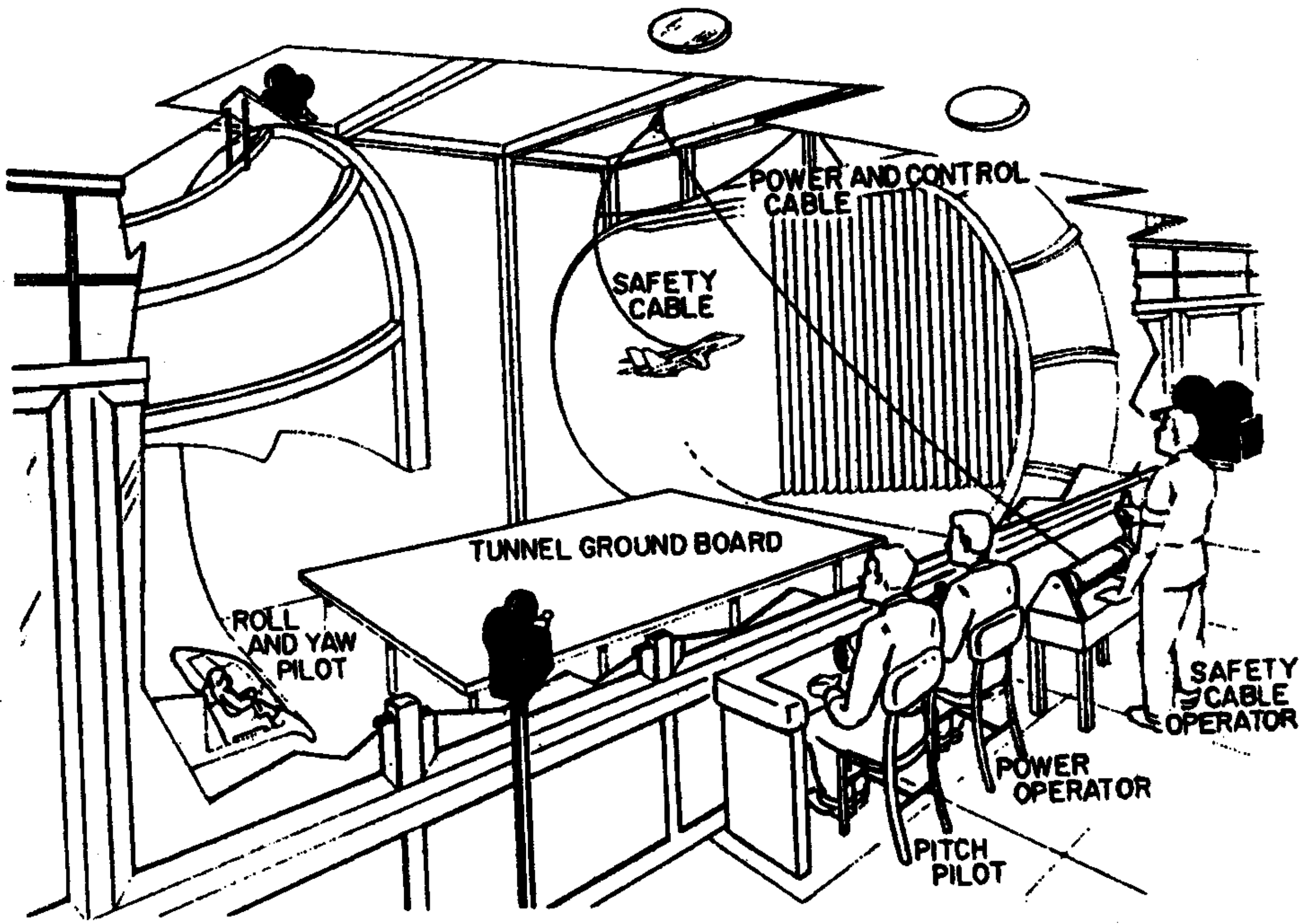

Figure 6 - Full-Scale Tunnel - Set up for Free-Flight testing
Source: NASA - Langley

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